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Stereoscopic Floating Image System Using Stereoscopic Display and Two Lenses

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The proposed technique uses a combination of two systems, viz. a three dimensional stereoscopic system and a two-lens system. This novel combined system successfully produces a stereoscopic floating image in mid air near the observer. The two-lens system produces a floating image from the stereoscopic image originating from the stereoscopic system, and the two lenses eliminate the defects of the floating lens and concave mirror. The experimental results show that the two lenses eliminate the defects of the lens and the concave mirror, so that the proposed system successfully produces a touchable stereoscopic floating image.

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I. INTRODUCTION

Floating-Image Displays have many applications including advertising and promotion, collaborative decision making and simulation, because these applications need a touchable 3D image like the real object. Today, there are many kinds of 3D displays, but the 3D images that they produce are not touchable. Therefore, many researchers are studying how to produce a floating image from a 3D image. In floating image displays, a large concave mirror or large lens is used to produce the floating image. However, the lens and concave mirror produce a defective image, because the magnifications of these two elements are not constant and the image distance is not linearly related to the object distance.

In this paper, we present a stereoscopic floating image system using a stereo display and two lenses. The two-lens system can display floating images a large convex lens or a concave mirror. The proposed floating image display provides an impressive feel of depth, and the produced image appears to be located in free space near the observer [1]. The stereoscopic display adopts the binocular disparity [7], because it provides good feeling of depth.

This paper is organized as follows. In Section II, we present the polarization-multiplexed display. Section III presents the defects of the floating lens and discusses the two-lens system. Section IV presents the experimental results obtained with the stereoscopic floating display system. Finally, we make our conclusions in Section V.

II. STEREOSCOPIC DISPLAY TECHNIQUES

To perceive a scene in stereo 3D, humans use two eyes in parallel on a plane perpendicular to that of the image (binocular vision). As the eyes are set apart (by 6.4cm on average), they view the environment from slightly different perspectives. The different images of a scene produced by the left and right eyes are called a stereo pair. Small differences in the location of corresponding points in the stereo pair images [11] give accurate information about the depth of objects in relation to each other. This difference is termed binocular disparity and is used by the brain to produce the effect of depth in the scene. Stereopsis is therefore the process of perceiving depth in an environment using images produced by binocular vision.

There are four basic techniques used in stereoscopic displays, viz. Color (anaglyph) [4,5,10], Polarization multiplexed [4,5,10], Time multiplexed [9,10] and Location multiplexed (HMD) [8]. Among these four techniques, one advantage of the polarization-multiplexed technique is that the observer can view the stereo image in full color and full resolution and does not need expensive active glasses. Also, polarization multiplexed displays are becoming fairly inexpensive and can have multiple viewers (each with their own headset) [12].

The polarization multiplexed display simultaneously presents the left image and the right image to the viewer. This display structure is illustrated in figure 1. In the two-display set-up, the left monitor creates the left image that is polarized at 45°, and the right image

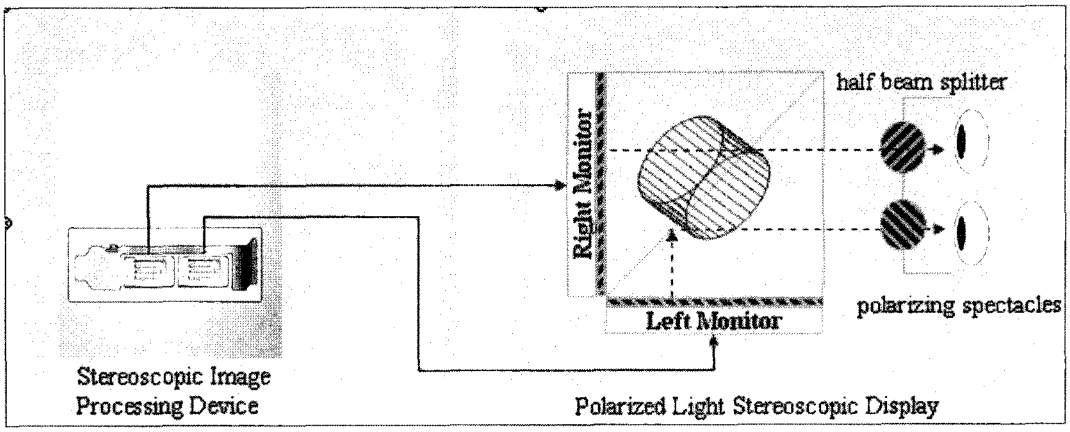


FIG. 1. Polarization multiplexed stereoscopic display structure.

monitor creates the right image that is polarized at 135°. A beam splitter (semi reflector) is used to channel the left and right images to the observer. When the stereo pair images from the two monitors are viewed through crossed-polarizing glasses, the left eye only sees the left image and the right eye only sees the right image. This allows the visual system to merge the two images, resulting in the perception of depth, or stereopsis.

III. LENS DEFECTS AND TWO LENSES

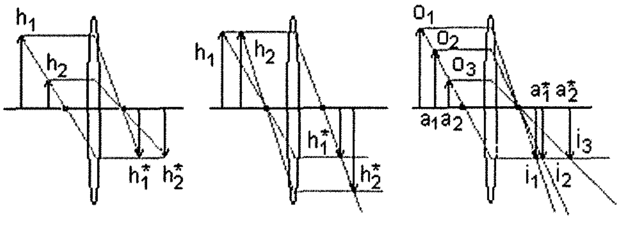
The convex lens and concave mirror produce defective images of objects, because their magnifications are not constant, and the image distance is not linearly related to the object distance. Herein, we discuss only the defects of the convex lens, because the problems posed by the concave mirror and convex lens are very similar. There are two kinds of defects associated with the convex lens: the height defect and distance defect.

For example in Fig. 2 (a), although the heights of the two objects are different, the heights of their respective images are equal ($h_1 \neq h_2$ but $h^*_1 = h^*_2$), while in Fig. 2 (b), the heights of the two objects are equal, but the heights of their images are not equal ($h_1 = h_2$ but $h^*_1 \neq h^*_2$)

In the case of the distance defect, the distance between the two objects differs from the distance between their images. For example in Fig. 2 (c), a_1 and a_2 are equal, but a^*_1 and a^*_2 are not equal, where a_1, a_2 are the distances between o_1, o_2 and o_2, o_3, respectively, and a^*_1, a^*_2 are the distances between i_1, i_2 and i_2, i_3, respectively.

The floating image system has two kinds of magnification. The first is the height magnification, which is defined as

$$M_h = \frac{imageheight}{objectheight}. \tag{1}$$



(a) (b) (c)

FIG. 2. Lens defects. (a) The heights of the two objects are different, but the heights of their images are equal. (b) The heights of the two objects are equal, but the heights of their images are different. (c) The distances between the objects are equal, but the distances between the images are not equal.

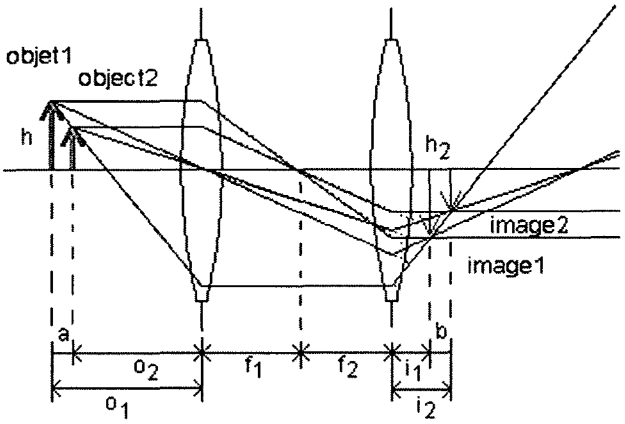


FIG. 3. Formation of two images using two lenses.

The second is the distance magnification, which is defined as

$$M_d = \frac{imagedis\tan ce}{objectdis\tan ce}. \tag{2}$$

The use of two lenses eliminates these lens defects, as shown in Fig. 3. When the distance between the two lenses is equal to the sum of their focal lengths, the two lenses eliminate all of the lens defects ($d=f_1+f_2$: where d is the distance between the two lenses, and f_1 and f_2 are the focal lengths of the first and second lenses, respectively).

According to Eq. 1, the height magnification in Fig. 4 is described by Eq. 3

$$\frac{h_2}{h}=\frac{f_2}{f_1}\Rightarrow M_h=\frac{f_2}{f_1}, \tag{3}$$

where h is the height of object 1, h_2 is the height of image 1, f_1 is the focal length of lens 1 and f_2 is the focal length of lens 2.

The relation between the image distance and object distance is given by

$$i=\frac{f_1 f_2(f_2+f_1)-f_2^2 o}{f_1^2}, \tag{4}$$

where o is the object distance, and i is the image distance.

According to Eqs. 2 and 4, we can determine the distance magnification as follows :

$$M_d=\frac{i_1-i_2}{o_1-o_2}=-\frac{f_2^2}{f_1^2}, \tag{5}$$

where o_1 is the distance of object1 from lens 1, i_1 is the distance of image1 from lens 2, o_2 is the distance of object 2 from lens 1, and i_2 is the distance of image2 from lens 2. The distance magnification ($M_d=-\frac{f_2^2}{f_1^2}$) and the height magnification ($M_h=\frac{f_2}{f_1}$) are equal when the focal lengths of the two lenses are equal ($f_1=f_2$). Thus, we can rewrite Eq. 4 as

$$i=2f-o. \tag{6}$$

From Eq. 6, we can see that the object position range is $0<o<2f$, the image distance range is $2f>i>0$, and the image maximum distance is 2f.

We can compare the two lenses system with the floating lens system, as shown in table 1.

TABLE 1. Comparison of two lenses system with floating lens system.

Parameters	Two lenses	Floating lens
Relationship between image and object distance	$i=2f-o$	$i=\frac{of}{o-f}$
Image range	0<i<2f	0<i<f
Image position	controllable	fixed
Height magnification	constant	not constant
Distance magnification	constant	not constant
Magnifications defend on	f	f, o, i

IV. EXPERIMENT

We conducted the experiment in two steps. In the first step, we checked the distance and height magnification of the two-lens system and the reducing defects of the floating lens system. In the second step, we merged the two-lens system with the stereoscopic display.

In the experiment, we used two Fresnel lenses and a camera, as shown in Fig. 4 (a). The focal lengths of the two Fresnel lenses are both 230 mm and the distance between them is equal to the sum of their focal lengths. The two lenses produce an image of an object that is rotated by 180°. According to Eq. 6, the object range is 0<o<460 mm, so the image distance range is 460 mm>i>0, and the maximum image distance is 460 mm.

The original object and the compared object are two identical papers. The width and height of the small quadrates on the papers are 5 mm. The right paper is the original object, and the left paper is the compared object that is on the line. The height magnification of the two lenses is equal to one, so the image size is the same as the object size. The experimental result is shown in Fig. 5.

The sizes of the left and right papers appear to be the same, so we can say that the height magnification of the two-lens system is equal to one.

We took three pictures after changing the object

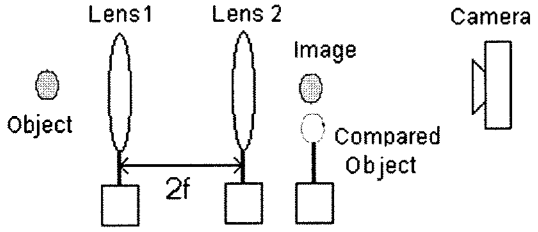


FIG. 4. Experimental set-up.

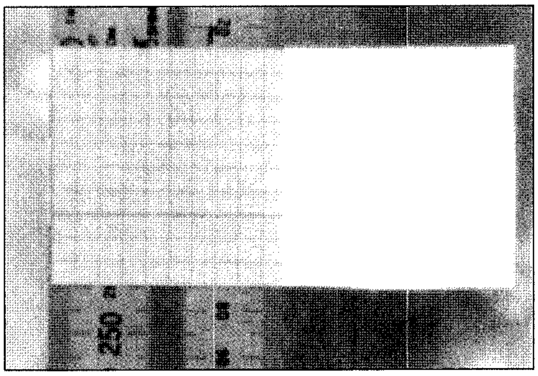


FIG. 5. Height magnification.

distance, as shown in Fig. 6. We always focused on the compared object and shifted the position of the object. In Fig. 6 (a), the object distance is 200 mm when the compared object and the floating image are in the same plane, and so the compared object and the floating image appear to be the same. In Fig. 6 (b), we shifted the object position by a distance of 100 mm (the object distance is 100 mm) from the first position toward lens1, so that the floating image looks bigger than the compared object. In Fig. 6 (c), we shifted the object position by a distance of 100 mm (the object distance is 300 mm) from the first position away from the first lens, so that the floating image looks smaller than the compared object. In Fig. 6, the relative size depth cue [4] can be perceived, because the biggest image is nearer to the observer and the smallest image is farther from the observer.

Also, when the two lenses produce a floating image

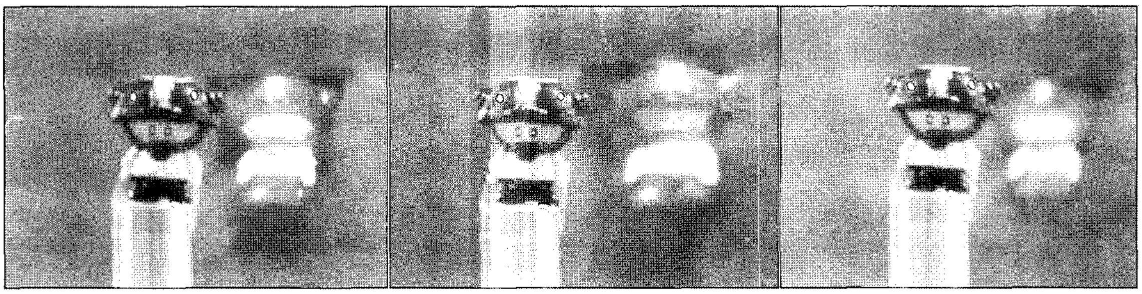

(a) (b) (c)

FIG. 6. Experiment result. (a) The object distance is 200 mm. (b) The object distance is 100 mm. (c) The object distance is 300 mm.

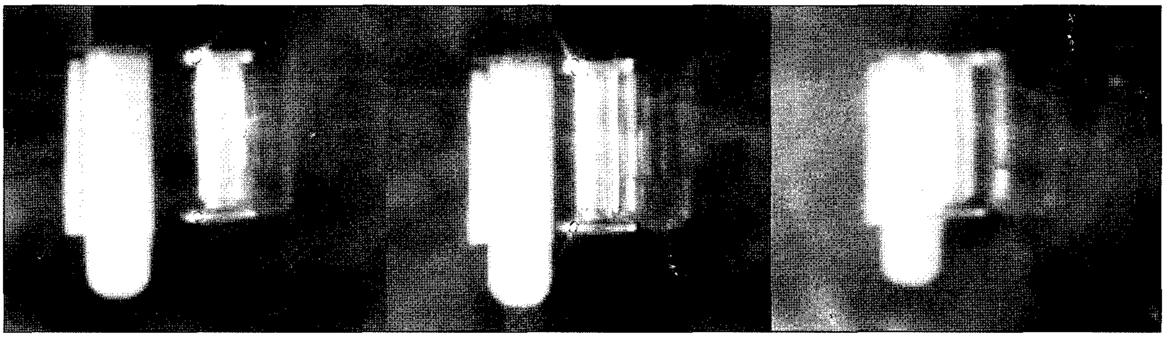
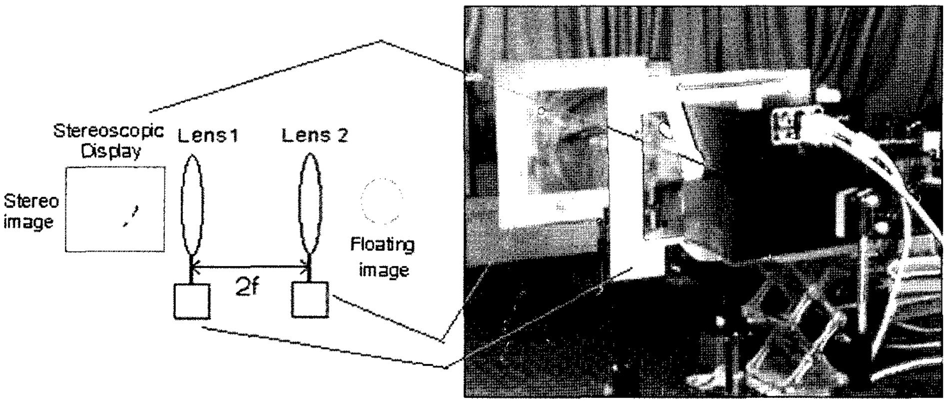

(a) (b) (c)

FIG. 7. Motion parallax depth. (a) Left view 10° (b) Center view. (c) Right view 10°



(a) (b)

FIG. 8. Experimental system. (a) Schema of the proposed system (b) Experimental setup.

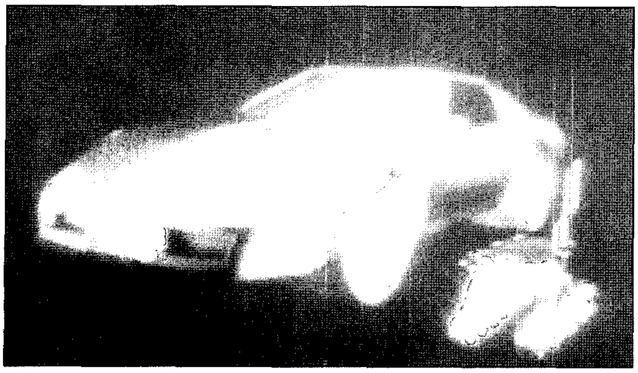


FIG. 9. Stereoscopic floating image.

from a real object, we can perceive the motion parallax depth [4,7], because the two lenses can change the image position. The motion parallax is a very important depth cue. Another experimental result is shown in Fig. 7.

In step 2, we combined the two-lens system with a stereoscopic display. Figures 8 (a) and (b) show a schema of the proposed system and the experimental setup, respectively.

Once the stereoscopic display successfully produces a 3D image, the two lenses project it from inside of the stereoscopic display to mid air near the observer. When the viewer looks into the system with glasses, he or she can perceive the 3D image that is located in mid air. Therefore, the proposed system can produce stereoscopic floating images. An example of a stereoscopic floating image is showed in Fig. 9.

V. CONCLUSION

The two lenses eliminated all of the defects of the convex lens and concave mirror, because the distance magnification and height magnification of the two lenses is constant and the image distance is linearly related to the object distance or 3D image distance.

Since we can change the distance between the first lens and the stereoscopic display screen, the stereoscopic floating image distance is able to be controlled. The floating image distance is not changeable when using a large convex lens and concave mirror, because the height and distance magnification depend on the image distance.

When the viewer wears the polarized glasses and looks at the stereoscopic floating image, he or she can perceive the depth cues and the floating image.

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